THE ROYAL AERONAUTICAL SOCIETY

MONTHLY NOTICES,

AUGUST, 1942.

Election of Members.

The following members were recently elected:—

Associate Fellows.—John Hanway Parr Brymer (from Graduate), Joseph Solvey.

Associates.—Teodor Dachowski, James William Fox, Raworth John Hill, Frank McKenna, Stuart Macfarlane, Brian Morley Temple.

Graduates.—Allan Geoffrey Cooper (from Student), William John Strang.

Students.—George Herbert Appleyard, Gunter Harry Berendt, Joseph Black, Robert Slayton.

Society Meeting.

It is proposed to hold a meeting of the Society to discuss "Methods of Performance Calculations." Will those members who would like to attend write in to the Secretary? The meeting cannot be arranged unless sufficient members express a wish for it.

Elliott Memorial Prize.

The Elliott Memorial Prize has been awarded to Aircraft Apprentice F. C. Bluett, who has obtained the highest marks in the General Studies Examination of the August, 1940, Entry of Aircraft Apprentices.

Graduates' and Students' Section.

The following lectures and discussions have been arranged to take place in the Library of the Society, at 4, Hamilton Place, London, W.1, as follows:—

Wednesday, August 12th, 7.30 p.m.—Informal Discussion with Mr. P. G. Masefield, M.A., A.F.R.Ae.S., in the chair

The subject has not been definitely decided upon, but the tentative subject is the course of the aerial war.

Wednesday, 2nd September, 7.30 p.m.—Lecture by Mr. L. Smith, on "Work in an Experimental Seaplane Tank." Mr. Smith is in charge of Messrs. Short Brothers Seaplane Tank.

Dr. J. Gott, A.F.R.Ae.S., will be in the chair.

Acknowledgments.

The Council acknowledge with grateful thanks the gift of Journals from Mr. W. S. Hollyhock, Associate Fellow, and Lord Sempill, Fellow.

Additions to the Library.

Pamphlets in italics, with location reference following in brackets.
Books marked * or ** may not be taken out on loan.

A.a.295.—How Aeroplanes Fly. By W. O. Manning. Oxford University Press. 1942. 2/-.

*B.a.258.—*Enemy Aircraft Do. 217 E-1.* (*Ministry of Aircraft Production, Official Reports.*)

*B.a.259-266.—*Leaflets describing early Aeroplanes: Avro (three issues), Blériot, British and Colonial Co., Farman, Humber, Nieuport, Sanders.* (Y.3.i.)

*B.a.268-269.—*Leaflets describing Austin "Whippet" and Beardmore Aeroplanes* (1920). (Y.3.ii.)

*B.b.20.—*Folder describing Bartelt Hélicoptère* (*Olympia Exhibition*, 1911). (PB.2.b.1.)

*B.c.58-60.—*Leaflets describing early Gliders and Pedal-craft.* ("*Kestrel*" *Glider, Cycloplane, Mark-Fan-Shutter.*) (Y.10.a.1a-1c.)

B.e.39.—Solid Scale Model Aircraft. By J. H. Elwell. Harborough Publishing Co. 1941. 3/6.

B.f.82.—*Birds—the Model Aircraft. By F. W. Lane.* (*Article in "The Aeromodeller," June*, 1942.) (Y.10.b.6.)

*B.g.115.—British, American, German and Italian Aircraft. Hutchinson and Co. 1942. 3/6.

*D.b.176.—*Handley-Page Air Services* (*London-Paris-Brussels*) *Time-Table* (*abt.* 1920). (PD.1/3a.)

D.b.177.—*Consolidation of Canadian Air Lines.* (*Press Release.*) *Canadian Pacific Air Lines, Ltd.* 1942. (Y.6.a.31.)

E.b.91.—Fundamentals of Vibration Study. By R. G. Manley. Chapman and Hall. 1942. 13/6.

E.c.25.—Properties and Strengths of Materials. By J. D. Haddon. Sir Isaac Pitman and Sons. (4th Ed.) 8/6.

**EE.b.64.—Folder containing early Aircraft Engine Catalogues (1909-1914).

EE.b.65-66.—*Duesenberg 4-cylinder 16-valve motor.* (*Two descriptive pamphlets, abt.* 1917.) (Y.7.d.D.)

*G.a.56.—Metallurgical Abstracts, Series II, Vol. 8, 1941. Institute of Metals. 1942.

G.e.J.23.—Fourth Report to the Alloys Research Committee. By Prof. W. C. Roberts-Austen. Institution of Mechanical Engineers. 1897.

G.f.28.—*Methods of Increasing Production by High Speed Arc Welding. By S. G. P. de Lange and E. S. Waddington. Philips Industrial, Ltd.* 1942. (PG.9.c.6.)

N.a.67-72.—Series of works by John Tyndall, published by Longmans and Co.
Light. 1873
Floating Matter of the Air. 1881.
Contributions to Molecular Physics in the Domain of Radiant Heat. 1872.
Fragments of Science. (Two Vols.) 1896.
Heat considered as a mode of Motion. 1865.

N.a.73.—The Forms of Water. By John Tyndall. Paul, Trench, Trübner and Co. 1892.

N.b.7.—Sound. By John Tyndall. Longmans, Green and Co. 1883.

Q.b.65.—Elementary Costing for Libraries. By "V. G. Pintress." A. J. Philip. 1942. 5/-.

Q.b.66.—The Literature of the German War, 1939—a Preliminary Classification. By A. J. Hawkes. A. J. Philip. 1941. 2/-.

*R.c.268.—*Neale's Captive Aeroplanes.* (*Advt. leaflet.*) 1910. (Y.11.ii.a.23a.)

S b.113.—War Pictures by British Artists (R.A.F.). Preface by H. E. Bates. Oxford University Press. 1942. 1/3.

S.b.114.—Winged Squadrons. By Cecil Beaton. Hutchinson and Co. 1942. 5/-.

S.c.9.—Germany's Air Force. By O. Lehmann-Russbueldt. Allen and Unwin. 1935. 3/-.

S.e.35.—*Gauges for Fire Engines and Trailer Pumps. Alfred J. Mann. David Harcourt, Birmingham.* 1/-. (PS.3.b.8.)

S.e.36.—*Air Sea Rescue. Official Air Ministry Publication. H.M.S.O.*, 1942. 6*d*. (Y.17.c.R.)

S.e.37.—Spitfire! (The Experiences of a Fighter Pilot.) By " B. J. Ellan." John Murray. 1942. 5/-.

S.e.38.—Bombers over the Reich. By Capt. A. O. Pollard. Hutchinson and Co. 1941. 10/6.

S.e.39.—Britannia has Wings. By Sir Archibald Hurd. Hutchinson and Co. 1942, 5/-.

S.e.40.—Malta at Bay. By R. Leslie Oliver. Hutchinson and Co. 1942. 5/-.

S.e.41.—Spitfire Pilot. By D. M. Crook. Faber and Faber. 1942. 5/-.

T.a.98.—Memoir of Augustus De Morgan. By Sophia E. De Morgan. Longmans, Green and Co. 1882.

T.a.99.—Biographies of Daniel Guggenheim Medallists, 1929-1936. Daniel Guggenheim Fund, 1936.

†T.a.37.—The Avengers. (Fiction.) By Charles Graves. Hutchinson and Co. 1942. 7/6.

†T.b.15.—Because of These. (Verse.) By Anthony Richardson. Hodder and Stoughton. 1942. 3/6.

TT.b.16.—Wings: an Anthology of Flight. Compiled by H. G. Bryden. Faber and Faber. 1942. 8/6.

*UU.c.—*National Advisory Committee for Aeronautics (U.S.A.) Technical Memoranda.* 1942:—

No. 1013. Recording rapidly changing Cylinder-Wall Temperature. By Adolf Meier. (From F.G.I., Jan.-Feb., 1939.)

No. 1014. Investigation of Lubricants under Boundary Friction. By E. Heidebroek and E. Pietsch. (From F.G.I., March-April, 1941.)

No. 1015. Statistical Analysis of Service Stresses in Aircraft Wings. By Hans W. Kaul. (From Jahrbuch, 1938, der D.L.F.F., Ergänzungsband.)

*V.2./14.—Transactions of the Chartered Institute of Patent Agents. Vol. LIX. 1940-1941.

**WB.1/17.—Aerocraft. (Magazine.) Vol. 1, No. 1, March, 1909.

*WB.15/67.—Journal of the Institute of Metals, Vol. LXVII. 1941.

**Z.e.26.—Folder of newspaper cuttings on Aeronautics (1909-1911).

J. Laurence Pritchard, *Secretary and Editor.*

THEORY OF AIRCRAFT UNDERCARRIAGES IN RELATION TO ABSORPTION OF INITIAL LANDING IMPACT.

By P. B. Walker, M.A., Ph.D.

§1. Introduction.

Many complex machines and mechanical systems have an ideal and abstract form which has been evolved from fundamental theory without reference to those engineering principles that are so essential in practice. Thus the heat engine has its Carnot cycle and the propeller its actuator disc. With these, and numerous other examples, the object is to provide a standard of reference, to give an ideal which can be approached but never reached and, most important, to indicate the fundamental limitations imposed by theory and prevent profitless investigations.

Something like this is attempted here for the undercarriage, but only in relation to its function as a device for absorbing initial impact on landing. Unfettered by practical considerations it thus becomes possible to indulge in theoretical but not necessarily unprofitable speculation.

The basic principles behind the familiar cantilever oleo leg are first considered and the conclusion is reached that the provision of a special energy absorbing device is the price that is paid for reliability and the certainty of effective operation. The need for energy absorption is then questioned and it becomes clear that, theoretically, energy absorption is not essential to achieve a landing without excessive retardation, even when the rate of descent at the moment of ground contact is high. Essentially the undercarriage has to change the direction of motion of the aeroplane, and it is of very small consequence whether the resultant velocity is slightly reduced, as it is with the cantilever oleo leg, or whether it remains constant so that no energy has to be absorbed. Unfortunately mechanisms that might effect this are difficult to design and it is considered impracticable to ensure positive and reliable operation.

If energy absorption cannot be avoided there is still a possibility of eliminating the special energy-absorbing device such as the conventional oleo unit. Without this there are already three energy-absorbing systems on an undercarriage, namely, (*a*) sliding on the ground, (*b*) the brakes, and (*c*) the accelerating wheel which can store kinetic energy. This line of reasoning gives rise to what is referred to as the "drag undercarriage," which relies upon the presence of a reasonable ground drag for successful operation. In the case of the cantilever oleo undercarriage, energy absorbed in the drag system corresponds merely to retardation of the horizontal motion of the aeroplane. In the case of the "drag undercarriage" the wheel (or skid) is pushed forward relative to the aeroplane by means of an inclined leg, and this extra forward motion, associated with the drag force, accounts for energy of descent just as certainly as a vertical oleo leg would.

Unfortunately this system is again found to be impracticable at first sight, although there are possibilities of development. The main difficulty is to ensure ground adhesion without complete seizure at the ground. Adequate ground adhesion can, however, be ensured by combining the drag undercarriage with a vertical oleo leg or its equivalent, to give what is here referred to as the "compound undercarriage." Although this arrangement requires the special energy-absorbing device, a large proportion of the energy of descent is actually absorbed by the drag system.

The " compound undercarriage " is arrived at by deductive reasoning on theoretical lines without reference to practical considerations. The result, however, is about the same as the articulated undercarriages which are in actual use. It is therefore appropriate to mention in this introduction the more important conclusions from the theoretical investigation, that can be applied to the practical form of undercarriage.

(*a*) Provided an adequate ground force is ensured from the moment of " touch-down "—and that appropriate to sliding friction on most surfaces is sufficient—considerable energy of descent will be absorbed by the drag system owing to the wheel being pushed forward relative to the aeroplane as the undercarriage closes.

(*b*) The loading actions associated with drag have always to be investigated in relation to strength, and it is important to allow for the fact that an energy absorbing unit that has been designed for zero drag, or as though it were part of a cantilever oleo strut, may be far from fully contracted for the design rate of descent.

(*c*) The brakes may or may not be applied at the moment of touch-down, but the drag of the accelerating wheel cannot be avoided, and the energy of descent absorbed by the drag system may well exceed that absorbed by the oleo unit.

(*d*) If the oleo system is designed for a given rate of descent, without regard to the drag system of energy absorption, the aeroplane may land at considerably higher vertical velocities without the undercarriage " bottoming."

(*e*) All the above remarks apply to an articulated undercarriage with a radius rod behind the oleo, i.e. in thrust. If the system is reversed and the radius rod takes tension, a considerably greater capacity of energy absorption will need to be provided in the oleo leg if the drag forces are appreciable.

§2. Shock Absorption and Energy.

§2.1. The Basic Problem.

An essential purpose of the undercarriage of an aeroplane is to act as a shock-absorber in respect of the initial impact of landing. The undercarriage has other functions, in their way perhaps equally important, but these are not under consideration. The phase of operation of the undercarriage to be investigated is, in fact, restricted to a clearly defined and critical period. This begins when the wheels first make contact with the ground, and ends when the aeroplane as a whole has ceased its descent and is momentarily at least, moving parallel to the ground.

In this limited sense the undercarriage has a definite duty to perform. At the moment the wheels make contact with the ground it must transmit from the ground a vertical force to the aeroplane as a whole, which retards the rate of descent and reduces it to zero in a limited vertical distance. During the whole period the forces and accelerations in the system must never become excessive and involve risk of structural failure or injury to personnel on board.

§2.2. The Vertical Buffer or Cantilever Oleo.

The most direct method of arresting the descent of the aeroplane after contact with ground is by means of some form of vertical buffer. This is rigidly braced against lateral forces and carries a wheel to enable the aeroplane to retain its forward velocity.* In principle the buffer may consist of a compression spring,

* Since the two units of a conventional main undercarriage are similar and symmetrically situated, it is proposed to assume a single unit for the sake of clarity and simplicity. A main undercarriage and a tail up landing is primarily envisaged, but the theory is applicable also to a tail wheel unit.

though in practice provision is made for energy dissipation to prevent excessive rebound. The cantilever oleo is a common example of this type of vertical arrester unit.

The vertical buffer or cantilever oleo has one important disadvantage and two advantages, all of which are often taken for granted. They are, however, important when alternative methods of arresting descent are under consideration, since it is shown later that they are not possessed in the same degree by any other system.

The disadvantage is that energy absorption is inherent in the scheme and in practice special provision must be made for its ultimate dissipation. This complication is, in fact, the sacrifice that must be made to obtain a system that is exceedingly reliable in operation, which is the first of the two main advantages. The mechanism cannot begin to operate until contact with the ground has been made. Thereafter there is available a limited amount of vertical travel which cannot be expended without producing the vertical force necessary to arrest the descent of the aeroplane. If, therefore, the onset of this force is delayed for any reason, as for example by the yielding of soft ground, the undercarriage does not close up until the appropriate ground reaction is produced.

The second advantage is also an essential characteristic of the method underlying this type of undercarriage. It can operate without any horizontal applied forces, and it functions in exactly the same way whatever the horizontal speed of the aeroplane may be. The energy-absorbing buffer is, in fact, merely the conventional device for bringing a body completely to rest, but is here arranged so that it affects only the vertical component of velocity.

In practice, of course, horizontal drag forces may act from the ground, but these are incidental complications that do not affect the principle of operation. Design difficulties may occur, however, on this account, since the horizontal forces may tend to produce excessive friction inside the shock-absorbing unit. These difficulties are not insuperable, and may even be reduced to a secondary consideration by substituting a lever action instead of a sliding action.*

§2.3. Energy of Descent.

The widespread use of the cantilever oleo, and the particular approach to the problem of arresting vertical motion with which it is associated, has given rise to certain conceptions of energy which are not quite accurate, and not applicable to the general problem without some reservation. The expression "energy of descent" is frequently used, and is the kinetic energy arbitrarily associated with the vertical velocity. Likewise "energy of forward (horizontal) motion" is the kinetic energy associated with the horizontal component of velocity. In reality, of course, there is only one form of kinetic energy and that is associated with the resultant velocity. It so happens that with the vertical cantilever oleo unit this practice is not likely to lead to difficulty, but before considering the more general problem it is necessary to abandon these conceptions of energy or to extend the convention to make it generally applicable.

The conception of "vertical" and "horizontal" kinetic energy is tantamount to giving kinetic energy certain directional qualities which it does not strictly possess. The sub-division of the true kinetic energy into two parts however, is numerically accurate since the sum of these is equal to the true kinetic energy. Each "component" of kinetic energy has, moreover, a definite physical significance. The "energy of descent" is equal to the work that would have to be done by a directly applied vertical force in reducing the vertical component of velocity to zero, and similar considerations apply to the horizontal system.

The terms "energy of descent" and "energy of forward motion" can therefore be given a precise meaning and there is clearly a case for continuing

* Provided the fore-and-aft travel of the wheel is small, the "Lever suspension" undercarriage is in the same category as the vertical cantilever oleo.

their use in connection with the more general problem if the arbitrary nature of their definition is properly appreciated. Thus the principle of the independence of vertical velocities, accelerations and forces, on the one hand, and horizontal velocities, accelerations and forces on the other, may be extended to include kinetic energy and work provided allowance is made for the possibility of transfer of energy from one system to the other. The vertical cantilever oleo is a very special case in which no such transfer can arise, since the vertical system is completely self-contained.

§2.4. Landing without Energy Absorption.

When the rate of descent is retarded by a vertical force directly applied from the ground, energy absorption is clearly necessary. It is interesting to remark, therefore, that energy absorption is not theoretically necessary for reducing the rate of descent to zero, as is readily seen when the initial stage of landing is viewed in another light.

When the wheels first make contact with the ground the aeroplane as a whole is moving in a direction inclined to the ground at some small angle. When the initial impact has been completely absorbed the aeroplane is then moving parallel to the ground. Intermediately it proceeds along a curved path as the direction of motion changes.

The essential process therefore is gradual change of direction achieved by motion in a curved path, and is not necessarily associated with energy absorption. It is in fact most unusual in general engineering for special provision to be made for energy absorption when a body has to move along a curved path.

In theory all that is required is a curved ramp, with appropriate maximum slope to ensure tangential initial contact, which is automatically placed under the wheel at the critical instant and produces a continuous change of direction of the motion of the aeroplane as a whole. For an engineering proposition, however, the equivalent motion would have to be obtained by a suitable mechanism carried on the aeroplane.

Such mechanisms may be designed as a mental exercise, but unfortunately are all likely to be impracticable for one reason or another. They are, in fact, assumed here to be quite impracticable and it is not proposed to discuss them. It is however instructive to note that the difficulties are mechanical and functional, and that there is no theoretical reason why energy should need to be absorbed in landing.

Mention might be made of the two fundamental difficulties that stand in the way of achieving this theoretical ideal. The first is that mechanisms which have no energy absorbing device such as a spring are essentially geometrical and can be operated with very small forces. This makes correct timing impossible and premature operation is likely to occur particularly if the aeroplane lands on soft ground or springy turf. Thus, for example, the curved ramp itself might be pressed into the ground without appreciable vertical forces being generated, although the relative motion between the wheels and the ramp would be the same as for a properly arrested landing. The equivalent mechanism would be liable to operate in the same way and might even be operated by inertia forces.

The second difficulty is the need for providing a forward horizontal force in circumstances where every consideration tends to produce backward forces. This forward force, however, is clearly necessary, since in order to maintain constant resultant velocity the horizontal component must increase as the direction of motion changes.

§3. The Drag Undercarriage.

§3.1. Energy Absorption by Drag Forces.

If a landing without energy absorption is considered impracticable owing to mechanical difficulties, the next possibility to explore is the retardation of descent

by a system which does not require a special energy absorbing device such as the oleo leg. To achieve this, ground drag forces with which are to be associated energy absorption, must be present. The actual method of absorption may then be by sliding friction on the ground, wheel brakes or the building up of kinetic energy of wheel rotation. These have the advantage that they are already available as energy absorbing devices provided the essential ground drag is present.

It needs to be emphasised that these devices will necessarily be concerned, in any case, with absorption of energy associated with retardation of horizontal motion, and the problem is to make them contribute also to the absorption of energy of descent. With the object of first establishing fundamental theoretical principles some rather hypothetical systems are put forward below. The conclusions reached can then be used in connection with more practical but more complicated systems.

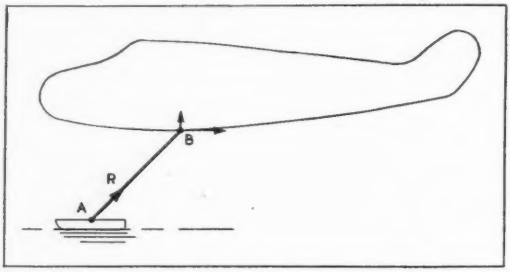


FIG. 1.

Drag undercarriage with simple skid.

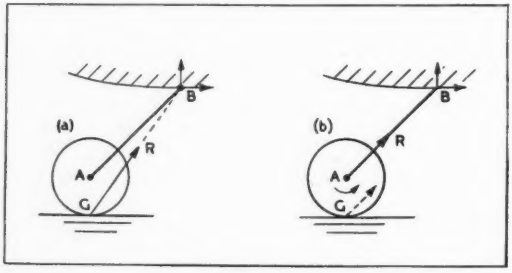


FIG. 2.

Drag undercarriage with wheels.

(a) Wheel locked by brakes. (b) Wheel accelerating.

§3.2. PRINCIPLE OF THE DRAG UNDERCARRIAGE.

In its simplest form the so-called drag undercarriage consists of an inclined leg sloping backwards and upwards from the ground (Fig. 1). The upper end of this leg is attached to the aeroplane by a hinged joint, and the bottom end is attached likewise to a small skid that slides along the ground. It is assumed at this stage that the ground reaction passes through the upper joint of the leg, an essential condition for equilibrium. It is proposed to ignore the weight of the undercarriage itself, and to assume that the leg is held in the appropriate position before ground contact is made and then released.

The descent of the aeroplane lowers the upper end B (Fig. 1) but is resisted by the vertical component of the thrust in the leg. At the same time the skid at

the lower end is pushed forward relative to the aeroplane, and it is this extra forward motion in conjunction with the horizontal component of the ground reaction that accounts for the absorption of the energy of descent.

The system behaves in a similar way when the skid is replaced by a wheel, provided sliding takes place at the ground. There are two extreme cases of this which may be compounded together. The first is that of the wheel locked by the brakes so that the ground reaction must pass through the point of ground contact and the upper joint of the leg (Fig. 2a). The other case is that of the unbraked wheel that is accelerating (Fig. 2b). Here the ground reaction must again pass through the point of ground contact, but this force is equivalent to an equal parallel force acting through the hub and a pure torque. This torque is absorbed in accelerating the wheel and leaves an effective force which must pass through the hub and the upper joint of the leg. Either system may operate without a tyre or with a very hard tyre, but the effect of the normal tyre will be to delay the onset of vertical force and to absorb some of the energy of descent.

§3.3. Limitations of the Drag Undercarriage.

So far as dynamical principles are concerned the operation of this system is quite sound, but it is doubtful whether the assumption that the ground reaction can be made to pass through the upper joint of the leg is justified. It is possible that mechanisms could be devised to achieve this, but the solutions given later scarcely come within the present terms of reference.

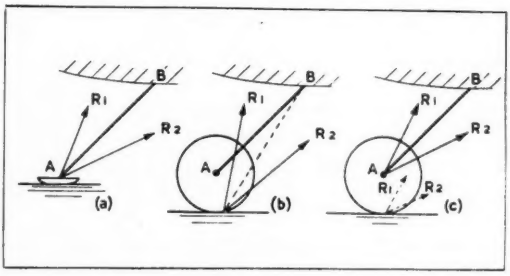


Fig. 3.

Drag undercarriage:—Non-adhesion (R_1) and seizure (R_2).
(a) Skid. (b) Locked wheel. (c) Accelerating wheel.

The direction of the ground reaction depends upon the coefficient of ground friction. For low values of the coefficient the resultant ground force will pass ahead of the critical point *B* that corresponds to the upper joint of the leg (R_1 in Fig. 3). This force, therefore, tends to lift the skid or wheel from the ground and the necessary ground adhesion does not exist and the undercarriage will not resist descent of the aeroplane.

The other extreme is a high coefficient of friction which gives a resultant force passing behind the critical point *B* (R_2 in Fig. 3). Here the skid or wheel is pressed hard into the ground with ever increasing force as the aeroplane descends and gives complete seizure of the system. Thus the motion of the aeroplane is violently arrested and structural failure is almost bound to occur.

§3.4. Controlled Horizontal Force.

If the system could be arranged so that the horizontal force has a predetermined value, the undercarriage would not suffer from the disadvantage considered above.

One method of achieving this is to apply a limited horizontal force to the hub by means of some form of arrester gear (Fig. 4a). For a given horizontal force

the problem becomes completely determinate and the vertical component will adjust itself so that the resultant force passes through the critical point. Such a system would operate best when the effective ground drag were negligible, as might obtain with a rolling and unbraked wheel. In any case it is necessary that the ground friction alone shall not be sufficient to produce seizure of the system.

The other method is a wheel with brakes having a torque limiting device (Fig. 4b). Given proper ground adhesion, this will operate in a similar way to the previous system, since the magnitude of the backward force will be limited. It is, however, essential for the ground friction to correspond to the seizure condition to ensure initial ground adhesion; otherwise the relief obtainable from the torque limitation is of no consequence. Sufficient friction to produce satisfactory adhesion, however, could not always be assured, and would in fact be avoided in practice wherever possible, since the brake torque limiting device itself cannot prevent seizure during the initial period while the wheel is accelerating.

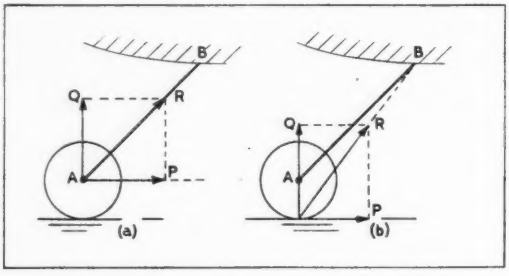


FIG. 4.

Drag undercarriage:—Controlled horizontal force.

(a) Special arrester gear. (b) Brakes with torque limitation.

It is therefore concluded that there is no simple practical way of directly controlling the horizontal force by a system carried by the aeroplane, and the only promising solution would involve an external device such as some form of arrester gear. The possibilities of a controlled vertical force are much more promising, however, and are dealt with below in connection with the "compound undercarriage."

§4. THE COMPOUND UNDERCARRIAGE.

§4.1. GROUND ADHESION.

The necessary ground adhesion for the drag undercarriage to operate under non-seizure conditions may best be ensured by the introduction of some form of yielding constraint into the system. When this is present the descending aeroplane always presses the wheel (or skid) hard against the ground.

There are several ways of providing the yielding constraint but one of the simplest and most practical requires a vertical compression strut or oleo leg (Figs. 5-7). The complete system, referred to as the "compound undercarriage," may thus be regarded as a combination of the vertical compression unit and the drag undercarriage.

The vertical compression unit must necessarily have capacity for energy absorption, and we have therefore departed from the original aim of avoiding a special energy absorbing device. It will, however, be shown that when the necessary ground drag forces are present the compression strut has to absorb must less energy than if it were acting alone as a cantilever unit.

Corresponding to seizure of the drag undercarriage is the tensioning of the vertical member of the compound undercarriage. Since this member is intended to absorb energy under the action of a compressive force and is normally designed to resist tension without appreciable extension, the whole articulating mechanism becomes virtually a rigid structure without any effective capacity for energy absorption. This condition of " seizure " is always to be avoided in practice and is assumed not to occur here.*

§4.2. Compound Undercarriage with Skid.

It is convenient to consider first the compound undercarriage with a simple skid (Fig. 5), since this illustrates the fundamental principles without the secondary complications associated with a wheel. The inclined ground reaction R may be resolved into two components: one acting along the vertical compression strut and the other along the rigid inclined leg. The force in the vertical member, however, is prevented from becoming excessive by the energy absorbing device, and the behaviour of this as the aeroplane descends determines the force in both members and the magnitude of the resultant ground reaction.

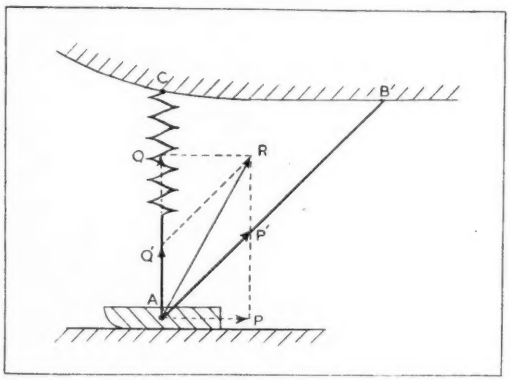


Fig. 5.
Compound undercarriage with skid.

The descent of the aeroplane is resisted by the vertical components of the compressive forces in the respective members. Energy of descent is absorbed in two ways. The vertical compression strut absorbs energy appropriate to the compressive force in the same way as for the simple system in which it is the only energy absorbing device. Energy appropriate to the drag force is also absorbed in friction as in the case of the simple drag undercarriage, and the contribution to absorption of energy of descent corresponds to the forward movement of the skid relative to the aeroplane.

When an appreciable ground drag force is present, therefore, the drag system absorbs energy that otherwise would have to be absorbed by the special energy-absorbing device in the vertical leg. This reduction may be considerable as may be shown for a typical case. If the compressible leg is truly vertical and the rigid leg inclined at 45°, then for a coefficient of friction of 0.5 the two systems absorb the energy of descent at equal rates. The relative rates of absorption will of course vary with change of geometry as the aeroplane descends, but this does not affect the basic principle.

As the coefficient of friction is increased the proportion of energy of descent absorbed by the drag system will increase, and the vertical ground reaction will

* Seizure of the compound undercarriage is dealt with as a separate problem in Appendix I.

tend to increase also. The extreme condition occurs when the ground reaction passes through the critical point, at which stage the drag system will theoretically absorb all the energy, but complete seizure will occur and the ground reaction tend to become infinite.

§4.3. Compound Undercarriage with Wheels.

The replacement of skid by a wheel introduces the usual complications. The simplest form has the two legs intersecting at the axis of the hub (Fig. 6), but if the vertical compressible leg can take the extra bending actions the rigid inclined leg may be joined to it at some higher point (Fig. 7).

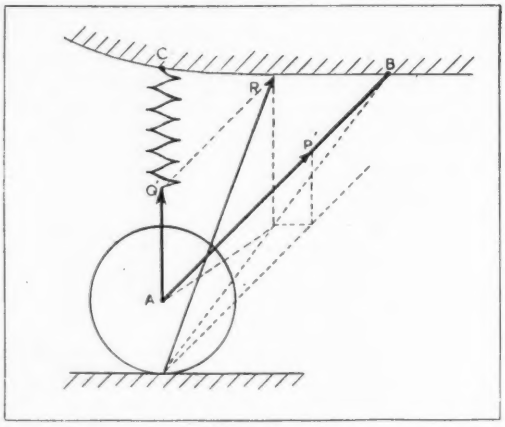


Fig. 6.

Compound undercarriage with wheel.
Force diagram for locked wheel.

The same general principles concerning energy absorption still apply except for the effect of the tyre. This, however, merely delays the onset of the vertical reaction and absorbs energy, but it does not directly influence the distribution of energy absorption between the two systems. Secondary effects are the slight change in geometry as the tyre contracts and the drag of the tyre itself when flattened.

The case of the wheel sliding on the ground is similar to that for the simple skid. If the wheel is locked by the brakes the ground reaction passes through the point of contact with the ground. If the wheel is accelerating the effective force passes through the hub. In general the vertical leg has to carry a bending moment depending on the height of the point of intersection (point A′ in Fig. 7) of the two legs. The lowest practical position is the centre of the hub, which still leaves a bending moment for the wheels-locked case, but gives zero bending moment for the accelerating wheel.

The presence of a bending moment on the compression strut complicates, of course, the problem of determining the loads in the respective members,* but does not materially affect the drag system of energy absorption. In particular, it is interesting to remark that, if the upper joints *B* and *C* lie on the same horizontal line at a given distance apart, the inclination of the rigid inclined leg does not itself affect the respective vertical components of reaction applied to the aeroplane.

Conditions are somewhat different when the wheel is rolling with brakes applied, but without sliding at the area of ground contact. The horizontal component of

* See Appendix II.

ground reaction is limited by the brake torque applied, and the vertical component tends to increase without any corresponding increase in the horizontal component. If the brake torque has a definite limitation the force in the inclined leg varies only on account of changes in geometry. Thus when the wheels begin to roll the drag system takes a smaller and smaller share of energy of descent as the aeroplane continues to descend and, in general, is not so effective as when the wheel is sliding on the ground. It should, however, be remarked that before the wheel begins to roll it has first to slide with locked wheels and then to accelerate to its rolling velocity, so that the aeroplane may well have ceased its descent when steady rolling begins.

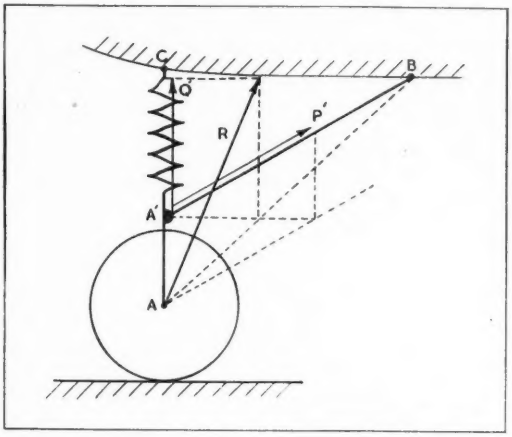


FIG. 7.

Compound wheel undercarriage (alternative arrangement). Force diagram for accelerating wheel.

§4.4. INVERTED COMPOUND UNDERCARRIAGE.

Mention should be made of the inverted form of compound undercarriage in which the rigid inclined leg is ahead of the compression strut. The energy absorption characteristics are completely reversed and the presence of a drag component increases the energy that has to be absorbed by the special unit provided on the compression leg. Thus whereas in the normal system, energy of descent is absorbed by the wheel (or skid) being pushed forward relative to the aeroplane, against the drag force, in the inverted system the drag makes what is virtually a negative contribution to the absorption of energy of descent.

This virtual negative is achieved in the following way. The drag system is in all cases absorbing energy corresponding to the retardation of horizontal velocity, and if the wheel does not move forward or backwards relative to the aeroplane, as in the case of the cantilever oleo, it makes no contribution towards the absorption of energy of descent. When the wheel is pushed forward relative to the aeroplane extra energy is absorbed and produces a corresponding relief to the special energy-absorbing device on the compression leg. When the wheel moves backwards relative to the aeroplane the energy absorption is reduced, and this reduction has to be compensated for by increased energy absorption in the compression leg. In other words the vertical component of tension in the inclined leg tends to pull the aeroplane downwards and increases the energy which the compression leg has to absorb.

Appendix I.

Note on the Complete and Partial Seizure* of the Compound Undercarriage.

If the vertical leg is inextensible and the resultant ground reaction passes behind the upper joint in the inclined leg the articulating system will lock completely, and the two legs will behave as a structure with the compressible leg in tension. Only the tyre can then prevent excessive forces occurring. To be really effective it would have to delay the onset of vertical ground reaction until the wheel had accelerated to its rolling velocity, but at least a considerable part of the valuable contribution which the drag system can make to the absorption of energy of descent would then be lost. Alternatively the tyre might have to act as the sole energy-absorbing device in regard to the initial descent.

Once the wheel has ceased to accelerate, but is rolling against the brakes, permanent seizure will never occur. The system will remain locked only until the vertical ground reaction has increased sufficiently to give, in conjunction with the limited horizontal force, a resultant force passing through the critical point, i.e. the upper joint of the rigid leg when the compression strut is vertical and the two attachments lie on the same horizontal line (see Appendix II). With further increase of vertical reaction the compression member will contract. Disregarding changes in geometry, the force in the inclined leg will then remain constant and the increase of vertical force will be taken entirely by the compression member.

When all the various factors are taken into consideration the necessity for avoiding the seizure condition is apparent. It is, however, difficult to control with certainty the coefficient of friction and the only effective variable is the position of the upper joint of the rigid inclined leg. Since braking is unlikely to lead to seizure, and will not do so if there is a torque limiting device fitted, the criterion may be taken to be the inclination to the vertical of the line through the centre of the hub and the critical point (see Appendix II).†

Even when overall seizure has been prevented, the tyre may play an important part as a safeguard against the consequences of temporary seizure produced by irregularities of the ground. Thus the face of a bump may incline the ground reaction further backward than would be the case with friction alone, and the tyre may then act as a relieving factor until the crest of the bump has been reached.

Appendix II.

Effect of Bending Actions and the Critical Point for Seizure of the Compound Undercarriage.

The bending actions which arise when the resultant ground reaction (or the effective ground reaction in the case of the accelerating wheel) does not pass through the intersection of the two legs, complicate the determination of the forces in the two legs. They also modify the criterion for seizure when the compressible leg is not truly vertical and when the upper joints of the two legs do not lie on the same horizontal line.

In Fig. 8 the member AA′C is one continuous member capable of acting as a beam with a pin joint at C. The member A′B is pin-jointed at each end. The applied force R acting at A is completely balanced by three forces:—

(*a*) *Force X at C*, acting perpendicular to CA.
(*b*) *Force Y at C*, acting along CA.
(*c*) *Force Z at B*, acting along BA′.

---

* "Seizure is not used here to refer to internal seizure of an oleo leg, but to the locking of the articulating mechanism."

† It is suggested that this angle should not be less than 45°.

It follows therefore that the reversals of these forces are together statically equivalent to the applied force R.

Line CB′ is first drawn perpendicular to AC, to intersect A′B at B′ and the line of action of the force R at H. The equilibrium of the system on or below this line is then considered as for a rigid body.

The applied force is represented in magnitude and position by AH, the scale of force being chosen to simplify the diagram. This force may first be resolved along A′H and B′H, and the force along A′H again resolved along A′C and A′B. If, therefore, H lies between C and B′ both compression strut AA′C and the rigid leg A′B are in thrust. If, however, H lies on CB′ produced the compression unit is in tension. Thus in general B′ and not B is the critical point for determining whether the articulating system will seize or not. In the special case where AC is vertical and CB is horizontal the points B and B′ coincide.

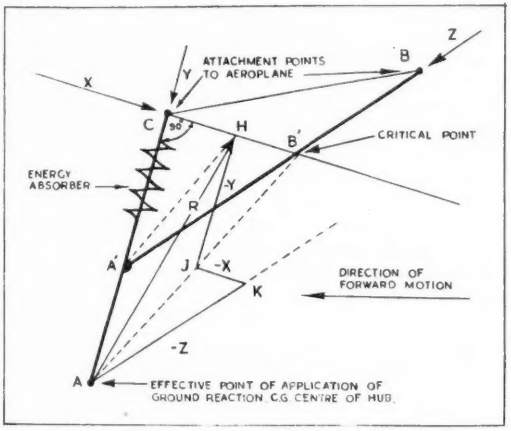


FIG. 8 (APPENDIX II).

Force diagram for offset ground reaction (general case).

To determine the magnitude of X, Y and Z, and hence the thrusts in the two legs, the following procedure may be adopted. The force AH is equivalent in magnitude and direction to AJ and JH, where line JH is parallel to AC and J lies on the line AB′. AJ is in turn equivalent in magnitude and direction to AK and KJ which are respectively parallel to A′, B′ and B′C. The successive resolution has then been so carried out that AH is completely equivalent to the following forces:—

(*a*) AK acting along A′B and equal but opposite to Z;
(*b*) KJ acting along B′C and equal but opposite to X;
(*c*) JH acting along AC and equal but opposite to Y.

This construction is also illustrated in Figs. 6 and 7 with simpler geometry for which B and B′ coincide.

THE HARDNESS TEST AS A MEANS OF ESTIMATING THE TENSILE STRENGTH OF METALS.

By W. J. Taylor, A.F.R.Ae.S.

When J. A. Brinell, at the end of the last century, interested himself in the property hardness of metals, he could have had no idea of the importance to be attained later by the new line of investigation he was launching nor of the interesting machines and their applications for which his work was to provide the inspiration.

In the aircraft industry this form of test is not solely used to determine the property hardness as such, but is used to give some idea of the maximum tensile strength of the material. This use is illustrated by some of the specifications controlling the quality of aircraft material, in which hardness tests are required on a specified percentage of bars to ensure that the bars which are not tensile tested will give a maximum tensile strength of not less than the minimum nor greater than the maximum specification values.

Another extremely useful feature of the hardness test is that it provides a ready means of checking the approximate tensile strength of finished parts or of pieces of material the properties of which are not known.

Although to date there are machines of many types that are capable of giving hardness values from which the tensile strength can be estimated, material specifications frequently specify the Brinell hardness number as the standard value. The various machines now available for this form of test are capable of giving reliable results, but owing to varying impressed conditions of test and other causes, the results may differ considerably from values obtained by the Brinell test. This fact is generally recognised and the British Standards Institution has published a specification (B.S.I. No. 860-1939) giving an approximate comparison of hardness scales.

Owing to the fact that the various " hardness " testing machines may not give the same value of hardness the author's experience over a number of years may be of interest to investigators who may be new to this form of test and to engineers who frequently require to know the tensile strength of small or large finished parts for which the material specification is unknown. The present article deals almost entirely with metals used in the aircraft industry and is based on hardness tests made strictly in accordance with B.S.I. specifications for hardness testing using the Brinell and pyramidal diamond (Vickers) machines.

Hardness Tests.

Among the many features which may influence the results of a hardness test are the following material properties:—

(*a*) Soft skin (decarburised surface of steel).
(*b*) Hard skin (cold worked material).
(*c*) Hardness gradients resulting from mass effect in heat treatment.
(*d*) Grain size.

In the Brinell test, in which a ball of standard diameter (10 mm.) and the load ratios given in Specification B.S.I. 240 are used, the amount of material displaced is relatively large and the accuracy of the result is not greatly affected by a soft or hard skin (nitrogen or carburised hardened surfaces excepted), when the test is made on an external surface, nor is the result greatly affected by grain

size in steels and light alloys. Hardness gradients due to mass effect in heat treatment, especially in material of large cross-sectional dimensions, may seriously affect the observed hardness value and may lead to an erroneous estimation of tensile strength. In all such cases it is best to prepare a cross section of the material and make the test midway between the core and outer surface; this will give an average value.

In some of the copper rich alloys, grain size and other micro-structural features may give rise to unrepresentative values of hardness, and lead to errors in the estimation of the tensile strength of the material.

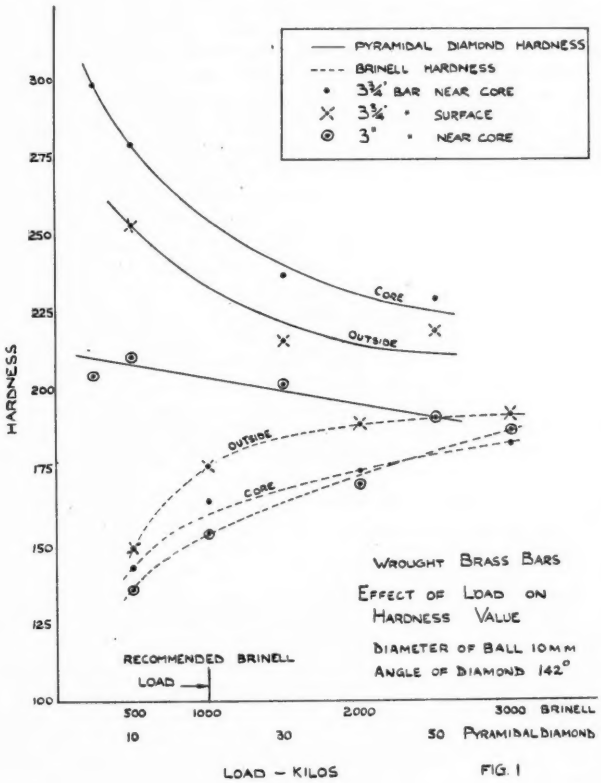


FIG. 1

Fig. 1 shows variation in the observed hardness of brass stated to be B.S.I. Specification 3.B.1. The tests were made using a 10 mm. ball and various loads on material near the outer surface and core of large diameter bars. On the graph are given also the results of pyramidal diamond hardness tests.

The curves show considerable variation in hardness as given by the two methods of test and under the various loads applied. Whatever the metallurgical reasons for this variation, the results show that the smaller the applied load the greater the difference in hardness value and that the larger the load the smaller the difference becomes. The curves further illustrate a non-agreement between the Brinell and the pyramidal diamond methods of test; particularly is this evident when low loads are used. Experience has shown that these two bars of brass which gave rise to this series of tests are not isolated cases, and it is

suggested that it is very necessary that a load ratio of 10, as recommended in B.S. Specification No. 240, should be rigidly adhered to particularly when obtaining hardness values for copper-rich alloys. If the mass of material is too small to permit the use of a 10 mm. ball with the appropriate load, it would appear desirable to select another standard size of ball such as 2 mm. dia.; this would enable the tests to be made in most machines whether designed primarily for pyramidal diamond or small ball hardness tests. The points and curves given in Fig. 1 emphasise the importance of the condition of testing in relation to the observed results for hardness of a copper-rich alloy.

Whilst the hardness test is not required by British specifications for this type of material, there is a practical engineering need for an estimate of the tensile strength on the basis of a hardness test. Considerable caution is required in making such an estimation and test data are necessary for conversion. Of the other types of wrought alloys used in aircraft construction, steel and light alloys appear to be less affected by the loading conditions used in the Brinell test; this view is confirmed by the Brinell tensile strength ratio which consistently remains sensibly constant for these wrought materials.

The application of pyramidal diamond hardness tests to metals is not confined to materials of small mass, but is widely used on finished parts, being for practical purposes a non-destructive test. In this test, which displaces a relatively small amount of material, the condition of the surface (excluding case-hardened surfaces by carburising or nitriding processes) can exert a big influence on the observed hardness of the material; work hardened surfaces of materials not subsequently heat treated and decarburised surfaces in heat treated unmachined steels tend to give higher and lower hardness values respectively than would be obtained if the surfaces were removed. To obtain true average values of hardness the test should be made on a cross section of the material or alternatively the suspected surface should be carefully removed to a depth of several thousandths of an inch. Where this is not possible, tests using two loads, low and high (the latter consistent with the rule covering the depth of indentation relative to the thickness of the material), will provide a clue as to the condition of the surface material, and afford a more accurate basis for estimation of the tensile strength. A typical example occurred some time ago when it was required to check the tensile strength of a considerable number of high tensile steel tubes by hardness tests. It was found that a number of these tubes had a decarburised skin, and without this knowledge a number of these tubes would have been rejected although they were actually of the required tensile strength.

Other surface conditions which would materially affect the hardness value, but which need merely be mentioned here, are those which include a surface protective against corrosive influences, such as aluminium-cladding on light alloys and non-ferrous coatings applied to steel. The coating on clad light alloys is not so easily detected by visual examination as are the coatings on steel.

A very common question is the relation between the Brinell and the pyramidal diamond hardness values. From the foregoing it will be seen that there are many factors affecting the results of both forms of test, so that it is not surprising that the relationship between these two forms of test is somewhat variable.

A number of plotted values obtained for various materials (which were of sufficient mass to permit Brinell tests as recommended in B.S. Specification No. 240 and using a 10 mm. diameter ball as well as pyramidal diamond tests) are shown in Fig. 2. They are mainly made on identical sections and are therefore comparable. Surface effects would not be involved as the tests were made on flats filed on the heads of tensile test pieces originally having threaded ends.

It will be seen that for almost all materials the pyramidal diamond tests give higher values of hardness than the Brinell test and that the values may be up

to 30 per cent. higher than the Brinell when assessed as a function of the Brinell hardness **value**

$$\frac{V_H - B_H}{B_H} \times 100$$

One feature of this collection of results is the apparent non-agreement between the Brinell and pyramidal diamond hardness of Armco iron, particularly in the annealed state, the pyramidal diamond hardness giving values approximately 5 per cent. and 20 per cent. higher than the Brinell. Armco iron, being one of the purest forms of iron, is sometimes expected to be uniform in hardness.

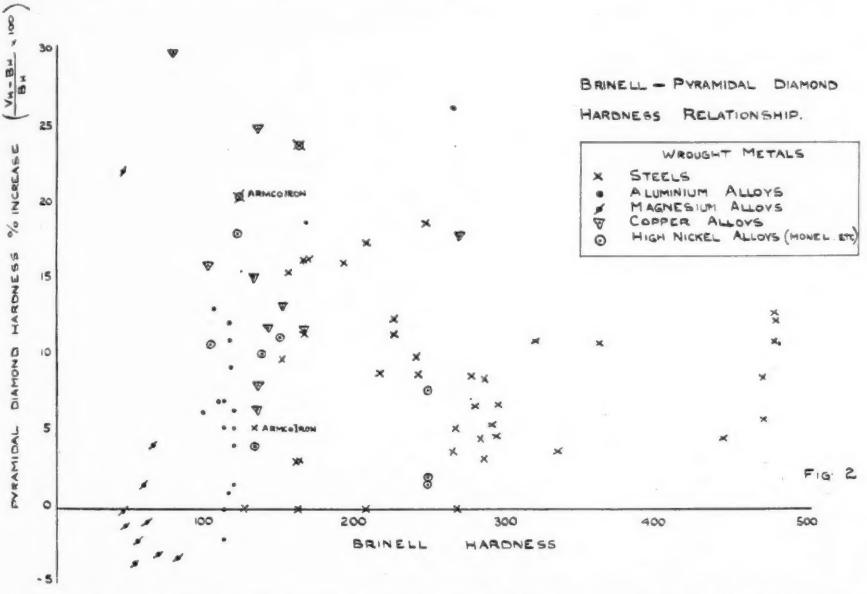


FIG. 2.

It may be of interest to record that the angle of the diamond used in all these experiments was 142°, but this angle, although being greater than the present standard angle of 136° cannot be entirely responsible for the generally higher values given by the pyramidal diamond hardness test, since some tests (1) made in America using three diamonds having angles of approximately 137°, 142° and 145°, using 30 kilos load on four steels of hardness ranging from approximately 200 to 950 showed that the greatest difference over this range was +2.7 per cent. for diamonds whose angles were 142° and 137°. Extrapolation of the plotted hardness angle of diamond curves suggests that if the angle had been 136° the greatest error would probably not have exceeded +5 per cent. for the 142° diamond. It is of interest to note, however, that in Fig. 2 the average hardness given by the pyramidal diamond indentation test used in these experiments is somewhere between 5 per cent. and 13 per cent. greater than the Brinell value and this difference is usually allowed for when the pyramidal diamond hardness value is converted into Brinell hardness; the reverse conversion is not so frequently required as pyramidal hardness tests can be made where the Brinell test cannot.

Estimation of Maximum Tensile Strength.

It will be apparent from what has been said above that a correct estimation of the tensile strength of a metal from a hardness test will, in the first instance,

depend on the accuracy of the hardness determination as representing the average value for the cross section of material concerned. Knowing the representative hardness value, it is not difficult to estimate the tensile strength of wrought steels and wrought light alloys from appropriate data.

In the absence of known published data, it is proposed to discuss this aspect of the subject fairly fully. For any class of material it is very necessary to possess a great number of actual values of hardness obtained for material of known tensile strength if a forecast is to be given with a fair degree of confidence; such a collection of values is given in Figs. 3 to 11 in which all the hardness values have been made on the ends of tensile test pieces whether they be of bar or sheet form.

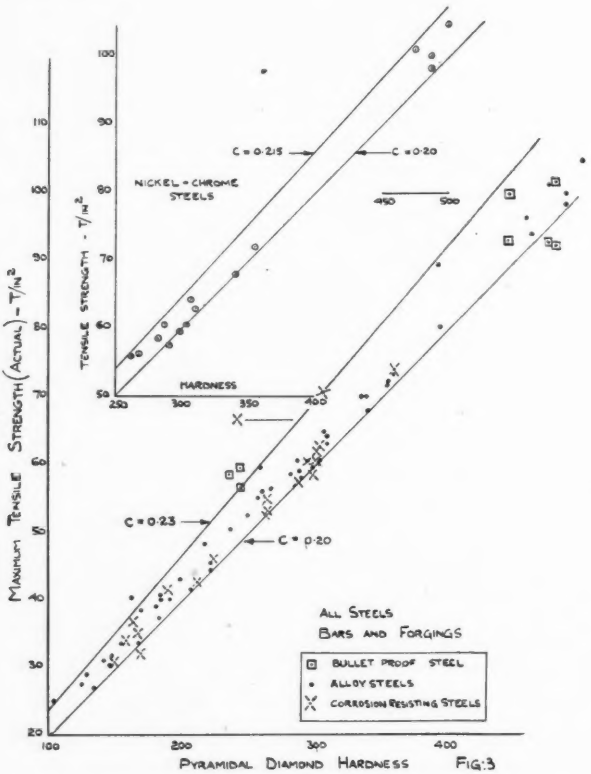


FIG. 3

For steels, the value of the factor C for converting Brinell hardness to tensile strength was suggested many years ago as being 0.21 to 0.23 for carbon or alloy steels heat-treated in relatively small masses and 0.23 to 0.25 for carbon and certain alloy steels annealed. These values are still reasonably accurate.

In aircraft construction, many parts are built up of material which is of thin section. Because of this, pyramidal diamond or like hardness testing machines are very popular for use on aircraft materials as they can be used for very small parts and for material of thicknesses as thin as 0.006 in. or even thinner with due allowances.

The general relation between the pyramidal diamond hardness and tensile strength of a number of steel bars and forgings is given in Fig. 3. It will be

seen that the plotted values lie between two relatively narrow maximum and minimum limits, the slopes of which suggest that the tensile strength can reasonably be expected to be between two calculated values using 0.20 and 0.23 as the value of C; thus on a steel whose pyramidal hardness is 250, the tensile strength may be expected to be between 50 and $57\frac{1}{2}$ tons/in.^{2}, this range of strength represents a possible ± 8 per cent. variation from the mean strength of 54 tons/in.^{2}. It will be noticed that the values for the majority of the corrosion-

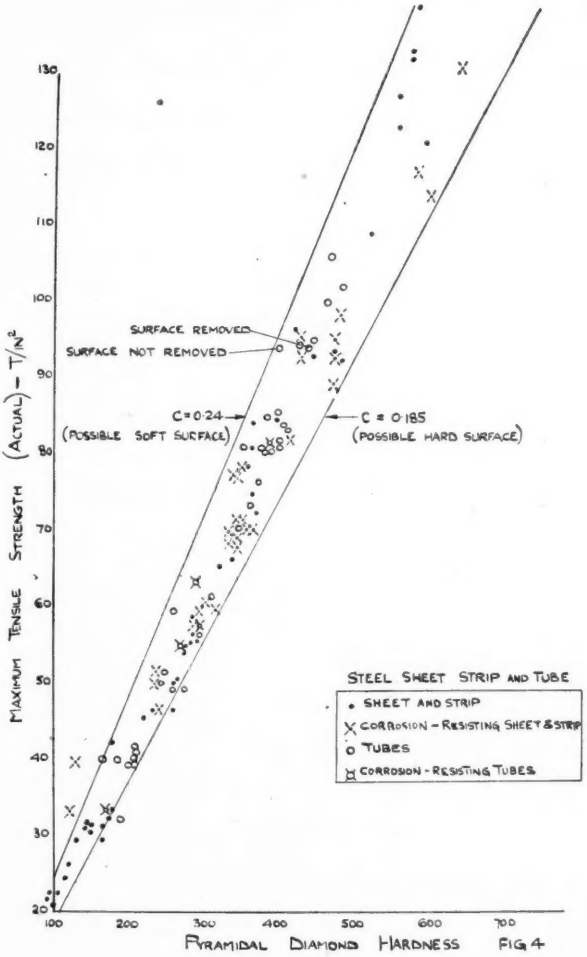
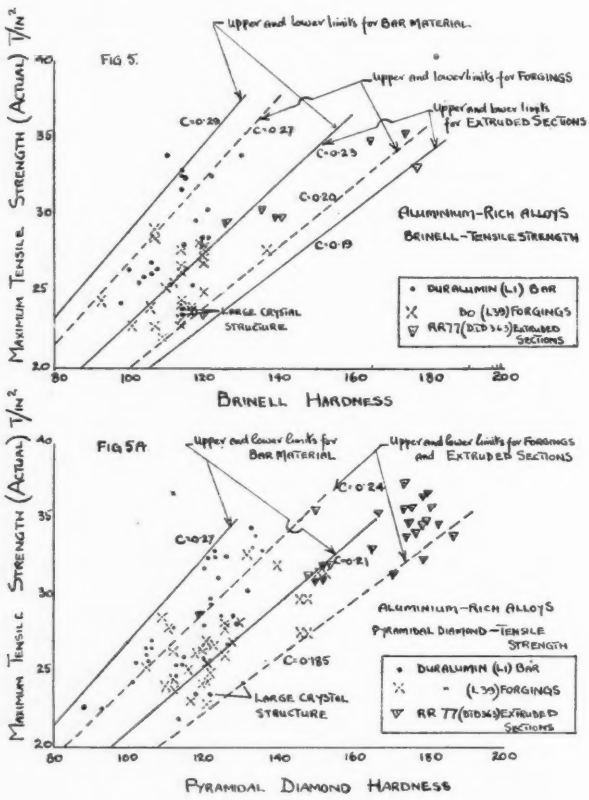


FIG. 4

resisting steels fall within the given limits (0.20 and 0.23), but with a tendency for the lower value of C falling to about 0.19. A closer estimation of strength may be possible by considering each class of steel separately, thus if the steel is known to be of the popular nickel-chrome variety the limiting values of C will be much closer. The insert on Fig. 3 suggests that the tensile strength can be forecast to about ± 4 per cent. of the mean strength by using factors 0.20 and 0.215. Included in Fig. 3 are a few results obtained for bullet proof steel plate.

The factors for steel sheet, strip and tubes are lower than the above values given for bar material, and the limits are wider. This is partly because strip and tube are usually of thin cross section and the surfaces may be either soft or hard depending on whether the material is of the drawn or hardened and tempered variety; further, in thin strip and tube it is often not possible to remove sufficient of the surface to ensure complete removal of the affected skin.

The relation between pyramidal diamond hardness and tensile strength of steel sheet, strip and tubes is shown in Fig. 4; the plotted values suggest that the upper and lower limiting values are 0.24 and 0.185 respectively.



Assuming that the wider range of limits has been influenced by the results of the hardness tests in which the condition of the surface of the material has played an important part, it is possible that the plotted values in the vicinity of the upper limit represent material having a soft (decarburised) surface and the values nearer the lower limit a hard (effects of cold work not fully removed) surface. Evidence of the former condition are the plotted values of the high strength alloy steels of above 90 tons/in.^{2} tensile strength which were obtained for two hardened and tempered materials, high carbon magneto springs and B.S.I. Specification T.2 for tubes; these lie in the close proximity to the line representing a value of $C=0.24$.

In one case the tensile strength is plotted against two hardness values, one a value for the decarburised surface and the other a value for the material well below the surface.

As stated in a preceding paragraph, the suggested limiting values are wide, but if the hardness tests are made on a cross section of the material, thus avoiding surface conditions, experience has shown that the limiting values can be taken as 0.19 and 0.215, and the percentage accuracy in this case will be approximately ±7 per cent., *i.e.*, the calculated value will differ by this amount or less from the mean tensile strength. It is doubtful if plotting the hardness tensile strength

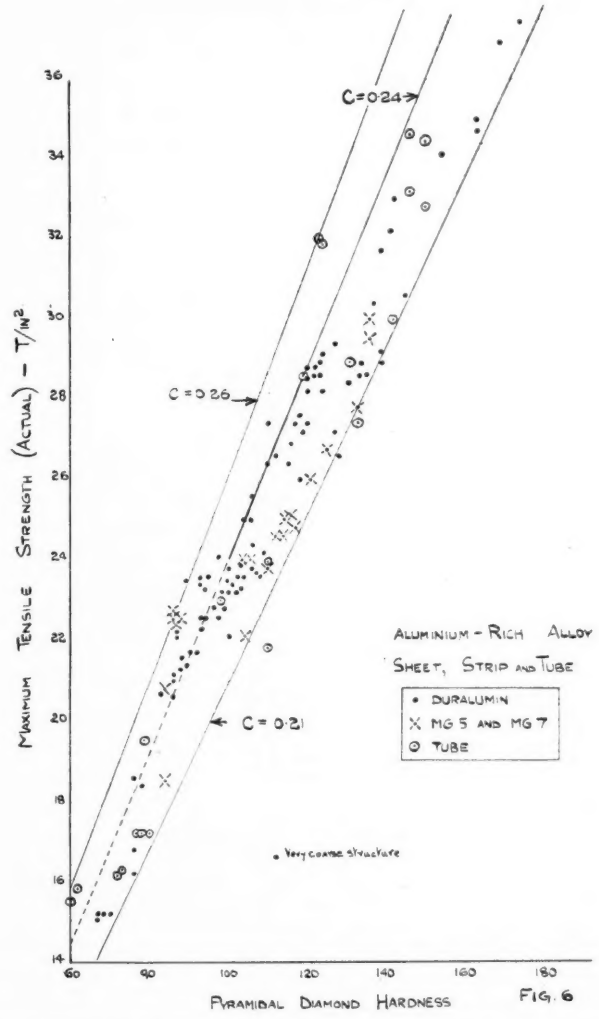
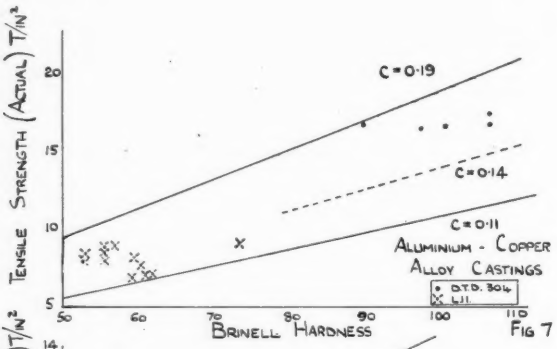


FIG. 6

values of steel sheet, strip and tube of a particular chemical composition or to a particular specification will provide closer limits because of the influence of the condition of the surface of the material on the hardness test result.

Light alloy bars are not affected by some of the factors influencing steel products and this class of material might be expected to show a closer relationship between hardness and tensile strength. Unfortunately this is not the case

as these materials often have relatively larger grain size than the ferrous materials and the local concentration of the hard constituents often varies considerably. This is liable to affect both the Brinell and pyramidal diamond hardness, and consequently the hardness-strength ratio as illustrated in Figs. 5 and 5a, in which it will be seen that the plotted values show considerable scatter. The suggested upper and lower limits of the factor C are 0.29 and 0.23 for bar, 0.27 and 0.20 for forgings and 0.23 and 0.19 for extruded sections when the Brinell test is used. When the pyramidal diamond hardness is determined, the



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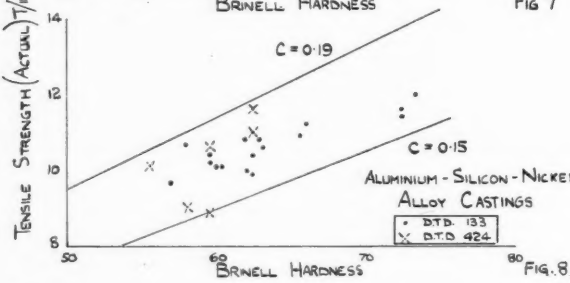

FIG. 8.

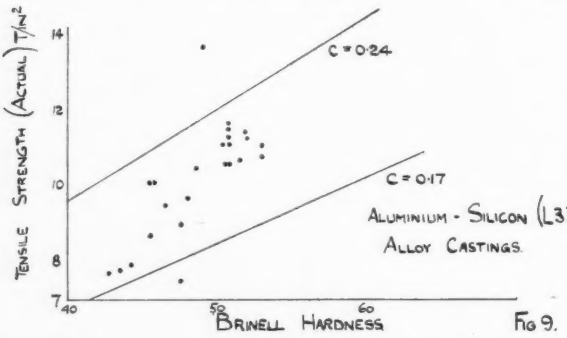

FIG 9.

limits suggested are 0.27 and 0.21 for bar, and 0.24 and 0.185 for forgings and extruded sections. In each case the range of limits might be suitably reduced in special circumstances.

For aluminium-rich alloy sheet, strip and tubes, Fig. 6, the limiting values of the factor are 0.26 and 0.21, but it is suggested that when the pyramidal diamond hardness exceeds 100 the upper limit may be reduced to 0.24; this

would provide relatively closer limits for material of 24 tons/in.^{2} and greater tensile strength.

The influence of grain size is illustrated by one plotted value which represents an average value of several hardness tests made on a very coarsely grained tensile test piece; fortunately this type of structure is not typical of normal solution heat-treated and aged sheet material, but the example serves to show that grain size may influence to some extent the hardness value and consequently the hardness-tensile strength ratio.

It is not possible at present to give, with confidence, factors for wrought magnesium-rich alloy materials, a small number (14) of test results to hand suggests that the factors for pyramidal diamond hardness tests range from 0.27 to 0.34. If these factors are confirmed by future experiments, it is interesting to note that the factors are much higher than those obtained for aluminium-rich alloys.

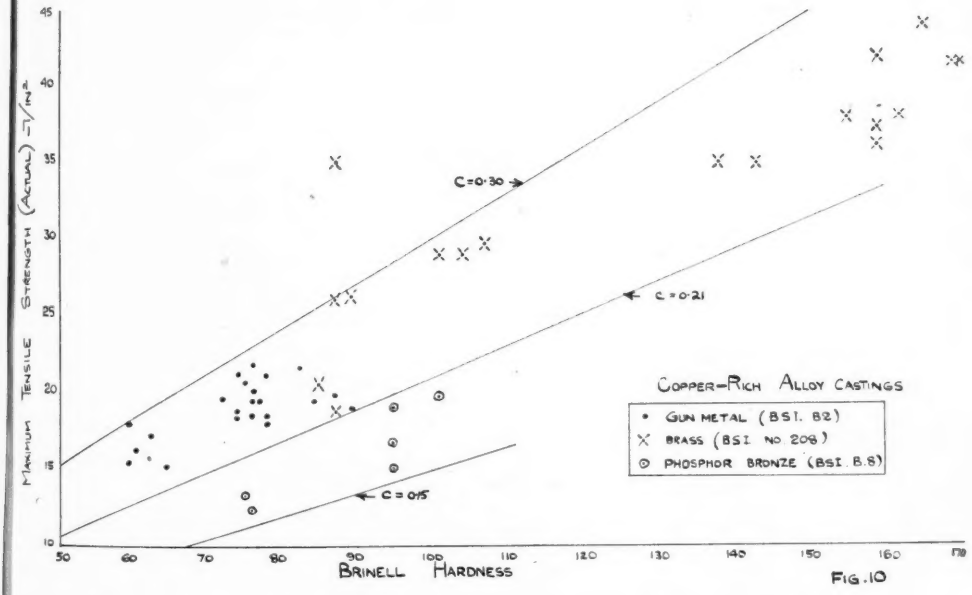

FIG. 10

Wrought copper-rich alloys are not used very extensively in aircraft structures and the author has very little information on the behaviour of this class of material. Information available suggests that great caution is necessary when attempting to forecast the tensile strength from Brinell and pyramidal diamond tests, shown by Figs. 1 and 2.

O'Neil in his well-known book (2) on Hardness Testing gives two widely different values, 0.26 and 0.35, as factors for converting Brinell hardness of wrought copper-rich alloys to tensile strength; the present author has also obtained a few values ranging from 0.19 to 0.31 (Brinell), and 0.18 to 0.29 (pyramidal diamond).

The estimation of tensile strength of castings is also a difficult problem. It is frequently desired to obtain an estimate of the tensile strength of a piece of a casting too small for preparation of a tensile test piece, or it may be desired to avoid cutting up the piece under examination. In view of this it is perhaps desirable to indicate the prospects of giving a satisfactory forecast.

The results of Brinell hardness tests made on the ends of fractured tensile test pieces indicate that the tensile strength of castings can be estimated between wide limits only, thus involving a large percentage difference from the estimated mean strength. Further, whilst the hardness test may be made on a relatively sound portion of the material, the tensile test piece may fracture at an unsound portion or vice-versa. Results obtained on some sand cast aluminium alloys are plotted in Figs. 7, 8 and 9; in each graph the plotted values are for material of the same chemical composition, but in some cases results for material in both the " as cast " and heat-treated conditions are included.

It will be apparent from examination of the graphs that if each condition was plotted separately closer limits than those selected would not be evident.

The upper and lower limiting values of the factor for alloys L.11, are 0.19 and 0.11, and for D.T.D. 133, D.T.D. 304 and D.T.D. 424, they appear to be about 0.19 and 0.14; for L. 33, 0.24 and 0.17. These factors indicate a percentage variation from the mean strength of about ± 15 per cent. and owing to the wide range can hardly be regarded as being of much practical utility.

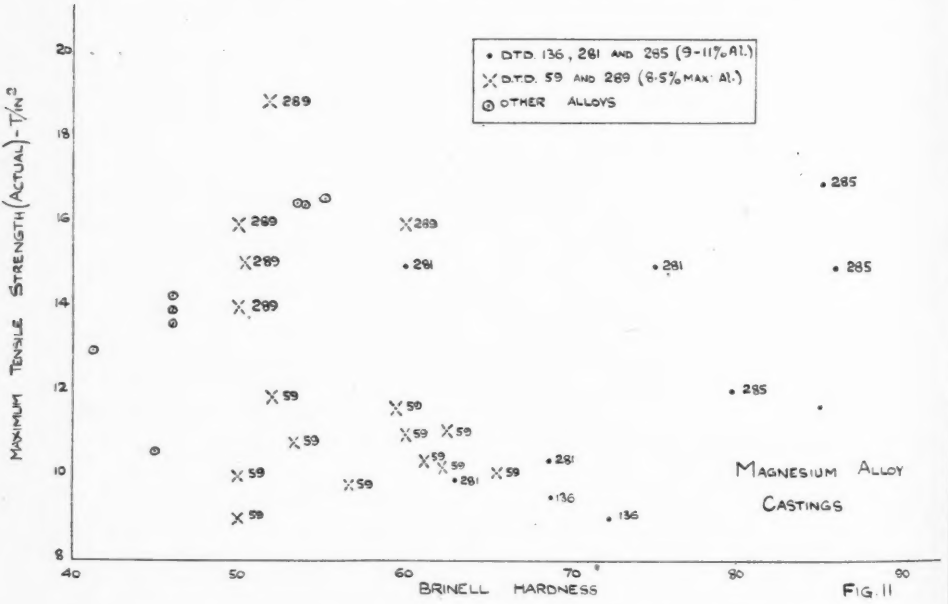

FIG. 11

The results on copper-rich alloy castings plotted in Fig. 10 also show some scatter; possible limiting factors for gun metal and brass are 0.30 and 0.21, and for phosphor bronze 0.21 and 0.15; the percentage variation from the mean strength is about ± 18 per cent. The values given here should be used with caution, owing to the small amount of experimental data, and only for the particular conditions of loading ($H_{10}/1{,}000/15$) used in these tests. The resultant estimation of tensile strength does, however, serve the purpose of indicating whether an alloy is of low or high strength. This may also be said of the aluminium alloy castings when considered collectively as a class.

The knowledge that a casting is of low or high strength or shows variation in strength from place to place is sometimes useful in determining the cause of service failure.

The information available for magnesium-rich alloys is very small, but the results given collectively and arranged according to chemical composition in Fig. 11 suggest that the Brinell tensile strength ratio is indefinite.

In all hardness tests of castings, a 10 mm. ball and loading conditions recommended in Specification B.S.I. 240 were used, as it is considered very undesirable to use conditions of test under which only a small amount of material is displaced.

The suggested factors for the various materials in relation to the two methods of hardness test can be summarised as follows:—

Material.	Brinell. Upper.	Brinell. Lower.	Pyramidal Diamond. Upper.	Pyramidal Diamond. Lower.	Fig.
Wrought steel bars and forgings (all steels) ...	0.25	0.21	0.23	0.20	3
" " " " (Nickel-chrome)			0.215	0.20	3
Steel sheet, strip and tube			0.24	0.185	4
Wrought aluminium-rich alloy bar	0.29	0.23	0.27	0.21	5
" " " " forgings ...	0.27	0.20	0.26	0.185	&
" " " " extruded sections	0.23	0.19	0.24	0.185	5A
Aluminium-rich alloy sheet, strip and tube {	Hardness	<100	0.26	0.21	6
"	"	>100	0.24	0.21	
Wrought copper-rich alloys	0.31	0.19	0.29	0.18	—
Gun-metal (B.2) and brass (B.S.I. No. 208) ...	*0.30	*0.21			10
Phosphor bronze (B.8)	*0.21	*0.15			10
Light alloy castings, L.11	0.19	0.11			7
" " " L.33	0.24	0.17			9
" " " D.T.D.133...	0.19	0.15			8
" " " D.T.D.304...	0.19	0.14			7
" " " D.T.D.424...	0.19	0.15			8
Magnesium alloy castings	Doubtful		Doubtful		

* Only for the particular conditions of loading used, viz. Brinell 10 mm. ball and load of 1,000 kilos.

Effect of Size of Diamond on the Estimated Tensile Strength.

As stated earlier in the article the angle of the diamond used for the above tests was 142° and the factors given apply for a diamond of this angle.

For the diamonds whose angles differ from the one used in these experiments, the factors given should be adjusted as follows:—

Angle of diamond.	Percentage of adjustment of factor *C*. Hardness not exceeding 230	340	600
136	Nil*	+5*	+3*
137	Nil	+3	+2
140	Nil	Nil	Nil
142	Nil	Nil	Nil
144	+4	+2	+4

* By extrapolation.

The percentage adjustment is based on the results of American tests (1) made on three steels of hardness approximately 230, 340 and 600

The author wishes to acknowledge permission of the Ministry of Aircraft Production to publish information contained in the article.

References.

1. The effects of variation in diamond indentors used in the Vickers Hardness Testing Machine. F. B. Fuller. Trans. of the American Society for Metals, Vol. XXV, No. 4.
2. The hardness of metals and its measurement. Hugh O'Neil.

REVIEWS.

AIRCRAFT IDENTIFICATION. BRITISH MONOPLANES, GERMAN MONOPLANES.

Temple Press. 1942. 2/- net.

This book, prepared by *The Aeroplane*, contains photographs and silhouettes of 32 British aircraft and 32 German aircraft. It gives, in fact, as concisely as possible the chief features and characteristics of the principal British and German aircraft now taking an active part in the war. It is more than ever important that as many people as possible should learn the differences between British and enemy aircraft and this is the kind of book which will enable them to do so. That it is edited by Peter Masefield, the Technical Editor of *The Aeroplane* and Editor of *The Aeroplane Spotter*, is a sufficient guarantee of its accuracy. By an ingenious printing lay out the book can be cut neatly in half so that the British and German aircraft each form its own complete section.

AIRFRAMES. A MANUAL FOR MECHANICS AND STUDENTS.

J. Campbell Corlett, A.R.Ae.S. 2nd Edition. Sir Isaac Pitman and Sons, Ltd. 1942. 6/-.

This is the second edition of a book first published in 1936, entitled " Rigging and Airframes." It is a book essentially useful to air mechanics, ground instructors and pupils of Flying Training Schools and Air Training Corps. Much of it has necessarily been re-written and new illustrations added.

Chapter I gives an explanation of general aeronautical terms; Chapter II, tools and instruments in general use; Chapter III, materials and types of construction; Chapter IV, assembly and trueing of component parts; and Chapter V, flying and taxying faults.

This is a useful book for those who should have at least an elementary knowledge of the construction and maintenance of the aircraft with which they are concerned.

MODERN TRIGONOMETRY.

M. J. G. Hearley, B.Sc. Nelson's Aero Science Manuals. T. Nelson and Sons, Ltd. 1942. 5/- net.

MECHANICAL PHYSICS.

Professor Herbert Dingle. Nelson's Aero Science Manuals. T. Nelson and Sons, Ltd. 1942. 5/- net.

WEATHER STUDY.

Professor D. Brunt, F.R.S. Nelson's Aero Science Manuals. T. Nelson and Sons, Ltd. 1942. 5/- net.

These are the first three of a series of manuals, under the general editorship of Professor H. Levy, which is intended to cover the whole field of the sciences underlying the principles of aeronautics. They are extremely well printed, cheap, and by authorities in their own sphere. All should make a wider appeal than to those studying aeronautics. Aviation calls upon almost every science for help and the manuals under review will bring home to many how varied those calls are.

"' Modern Trigonometry " covers the trigonometrical field up to and including the solution of triangles. The value of this book lies in the great number of examples, although one does not always agree with the answers given. For example, a series of questions are given on " What units would you choose to

measure the following?" and among them is "the height of a man." The answer is given in "inches," but surely one would not say a man is 70 inches in height? In Exercise 2, on page 30, the answer is only correct for the first and fourth quadrants, the value decreasing in the second and third quadrants as the value of the angle increases. These are minor slips, however, which do not detract from the usefulness of the book.

"Mechanical Physics," by Professor Herbert Dingle, covers Physical Measurements, Properties of Matter, Heat, and Vibrations and Sound. It is, in short, a general study of physics which may be equally useful to those who are studying that subject or to those specialising in aviation. It is fundamentally a book on physics and not physics applied to aviation. Nevertheless, physics enters so largely into certain aircraft problems that a sound knowledge of the subject is necessary for those engaged on such problems.

Professor Dingle finds, quite rightly, a difficulty in defining physics and considers the least unsatisfactory definition is that it is the study of measurable things. That covers, of course, the universe, and does not leave out much.

The author, however, has the faculty of easy writing which is also easy reading. He does not hesitate to give the common touch to his subject, as, for example, in his chapter on the Measurement of Time. "The introduction of Summer Time," he writes, "is sometimes thought to be an interference with nature. This is a mistake. We can adjust our arbitrary records of time to conform to our habits, or we can change our habits in order to maintain our arbitrary system of time-recording. This is our own affair. . . . So tenacious are we of our habits that it is found easier to tamper with the clock than to interfere with them."

Again, in dealing with the efficiency of the Carnot Cycle, the Professor emphasises the independence of the cycle of the working substance of the engine. "Of course," he adds, "in practice it would be more convenient to put a gas than, say, a collection of guinea pigs in the cylinder, but the same principles hold good in the two cases."

A book to be recommended.

Professor Brunt has aimed at writing a simple textbook of Meteorology suitable for readers with little or no previous knowledge of the subject.

In his Preface Professor Brunt adds, "I had particularly in mind the needs of Air Force Cadets and others whose interest is largely aeronautical. . . . I have included some material which at first sight might be considered too technical for the class of reader I have mentioned. But I find it difficult to believe that modern young people, who master the complexities of a radio receiver with ease, will fail to grasp the physical principles involved in Meteorology when those principles are stated simply."

The argument is an odd one. There are many complex subjects for study, biology, chemistry, engineering structures, and so on, but an ability to grasp one of these subjects is no criterion whatever that other subjects should prove just as easy to grasp, if the mind is applied to them.

It is by making this assumption that Professor Brunt has written a book which, excellent though it is, fails to provide that "simple textbook of meteorology suitable for readers with little or no previous knowledge of the subject." It is rather like an extract of meat, a little goes a long way, and the book requires close and careful reading, a little at a time, to digest the concentrated information given.

The weather is of very considerable interest to most people in the British Isles, and in the absence of weather reports at the present time Professor Brunt would have added considerably to the value of this book if he had given a chapter on local weather forecasting tips. This book, as one would expect from Professor Brunt, is first class, but it would more aptly have been called "Meteorology" instead of "Weather Study." The subjects may be the same, but the approach,

for those who know little about weather forecasting and want to know what the weather will be like during the day, is different.

AIRCRAFT WELDING.

L. S. Elzea. McGraw Hill Book Company, Inc., New York and London. 1942. 14/-.

The author has had many years' experience in the welding departments of a number of American aircraft factories in America and also as an instructor of welding to students. The book is entirely devoted to oxy-acetylene welding, electric welding being reserved for another book.

Chapter I deals with equipment, Chapter II with tools, and Chapter III with materials. In Chapter IV are descriptions of weld characteristics and types, illustrated with some excellent photographs of welds. In the following chapter the effect upon welding on the stressed condition of the material is discussed and the importance of the preliminary design on the ease and safety of welding. Chapter VI deals with jigs used in welding, and Chapter VII with methods of construction. The difference between aluminium and steel welding is dealt with in Chapter VIII.

Chapter IX, the longest chapter in the book, is also probably the most important. Entitled " Problems in Aircraft Welding " it provides just that practical information about various kinds of welds in steel and aluminium which should prove invaluable to the welder. Thirty-one problems of welding are dealt with in this chapter with many excellent photographs of good and bad welding. It is always a moot point, by the way, whether the wrong way of doing anything should be shown. The reviewer is of the opinion that only the right way should be given, and the student taught that any other way is incorrect and leads to trouble.

" Aircraft Welding " is beautifully printed and can be recommended.

ARISE TO CONQUER.

Wing Commander Ian Gleed, D.F.C. V. Gollancz. 1942. 8/6 net.

There is a greater difficulty reviewing books about the war while the war is still on than reviewing them in the saner days of peace. What will be readily assimilated by a war public would be rejected by a peace public.

Here is one of those books which it is difficult to place in its proper perspective. First of all, let it be said, that it is not what the publishers blurb tells us it is. " The author has the necessary power of making us identify ourselves with the air crews, until we feel that it is *we* who are taking-off to intercept German planes, and *we* who are wheeling and manœuvring and fighting in mid-air." We don't.

The author is obviously a better pilot than he is a writer. He has, indeed, a great story to tell, and if the reader can face the monotony of repetition he will learn much about those last pre-hectic days in France and the Battle of Britain, and raids over enemy airfields in Northern France. There is much that is worth reading, much that is waste of paper and print. The swearing is poor and the references to the Deity monotonous in their frequency.

SPITFIRE! (THE EXPERIENCES OF A FIGHTER PILOT).

By Squadron Leader " B. J. Ellan." John Murray. 1942. 5/-.

This is a book to be read at a sitting—most readers will continue sitting until on page 99 the author cheerily bids them " so long!" and will wish there were another hundred pages to follow. The matter is not new, for by now the stirring tale of the Battle of Britain has been told and retold; the style is that of a club magazine, irritatingly peppered with exclamation marks and the confusing initials demanded by the tradition of Service anonymity; yet with all this, the impression

left is one of charm. Perhaps this is due to the author's knack of transmitting the atmosphere of youth and keenness that permeated his squadron; their matter-of-fact acceptance of situations that any non-flyer would inevitably dramatise. We read of a pilot landing just as the author and a friend were describing how they had seen him shot down. " Didn't you go into a spin when that Hun had a crack at you?" asked G——. " Oh, yes, but I came out and everybody had disappeared, so I came back." G—— and I looked at each other: " I wish you wouldn't give people such frights," said G——, " I thought he'd got you." Of the same calibre is the wounded pilot who remarks " amidst roars of laughter ": " I thought I was dead, then I saw some more tracer coming past me, so I came to the conclusion I must still be alive." The author has a particularly soft spot in his heart for the Flight Sergeant " Grumpy "—so-called because, when passed over in a selection for flying on the first patrol " he stood looking at me with a hurt expression on his face, for all the world like a dog who has been told he can't come for a walk." Grumpy, on a subsequent occasion, when ordered to rejoin formation, ignored the command until he had shot down a Henschel. Taken to task later, he explained with a sly grin: " I must have had my R/T switched off, Sir!" We are left with the feeling that with men like these to guard us we can sleep quietly in our beds at night—and with the regret that only the initiated can supply names to the—as usual, perfectly recognisable—group photographs that illustrate the book. In addition to the portraits, there are many beautiful and striking photographs of aeroplanes in action.

BECAUSE OF THESE: (VERSES OF THE R.A.F.).

By Anthony Richardson. Hodder and Stoughton. 1942. 3/6.

The best compliment one can pay to these verses is to say that if they were slipped between two volumes of Rupert Brooke, bound in a similar style, any lover of the older poet might pick them up and read them for a while without realising his mistake. Here are all the qualities of Rupert Brooke's earlier poems; youthful irony alternating with wistfulness; a love of the English countryside, a feeling for beautiful words, and a command of rhyme and rhythm that sometimes breaks out in flashes of real poetry.

" The night when you went in low, the moon was grey,
Like an old nun's face a-dying. . . ."

In " Lines to a Widow " we find the vein of bitterness mingled with sentiment that runs through " The Chilterns," and beside the famous:—

" If I should die, think only this of me. . . ."

we may well set Anthony Richardson's epitaph to an Air Gunner:—

" He will not sing again this half of light,
They stilled his voice one night above Cologne.
But when the Devon sun in spring is bright,
There is a valley with a voice its own."

WINGS: AN ANTHOLOGY OF FLIGHT.

Edited by H. G. Bryden. Faber and Faber. 1942. 8/6.

A review of any anthology inevitably takes one form: quotation of passages which the reviewer personally approves, regrets for others which he personally would have included; mention of what he personally would have rejected in order to make room for them. For anthologies, after all, are a matter of individual taste. The compiler of this one has a catholic taste. We have the impression that, over a period of years, he has never read a book, magazine, or even newspaper, without having a pencil, scissors and notebook ready to hand; that when any striking passage, or even phrase has caught his eye, he has said to himself, " I like that!" and rushed to put it down before it eluded him. There is some-

thing for everyone here—though we doubt whether the airship man will be satisfied with a poem describing that most statically graceful of aerial creations as " a great white monster slug!" From Aeschylus and the Persian Ferodosee to Winston Churchill, from the Bible to *Punch*, the extracts, both prose and poetry, range in a well-ordered profusion. We find, as usual, that the best poetry about flying is written by those who do not practise it—and in many cases before actual flight became possible. It is a curious fact that flying—at first sight the most inspiring of professions—has so far produced only one great poet-pilot, Gabriele d'Annunzio, primarily a poet and only incidentally a pilot, and one great pilot prose-writer, Antoine de Saint-Exupéry, who is here represented by one of his finest passages—the death of Mermoz. No one who has ever lost a friend in the air (and which of us has not?) could read unmoved the closing words: " Slowly the truth was borne in upon us that our comrades would never return, that they were sleeping in that South Atlantic whose skies they had so often ploughed. Mermoz had done his job and slipped away to rest, like a gleaner who, having carefully bound his sheaf, lies down in the field to sleep."

SPITFIRE PILOT.

By D. M. Crook. Faber and Faber. 1942. 5/-.

If this book leaves a somewhat fragmentary and unsatisfying impression on the reader, the fault is not the author's. In reading a novel we know that all the characters who matter will be alive, at least till within a few pages of the end; in these narratives of the fighter pilots, one personality after another emerges, only to disappear with breath-taking suddenness. The story of 609 squadron is summed up succinctly in the early pages: " Within a few months, out of these fifteen friends, five had got the D.F.C." (the author, incidentally, among them) " and eight, alas, were dead." The cumulative impression, however, is not so much of regret for the dead as of pride and excitement in achievement. The author is one of those not too imaginative pilots who really enjoy fighting: " I think that these moments just before the clash are the most gloriously exciting moments of life. You sit there behind a great engine that seems as vibrant and alive as you are yourself, your thumb waits expectantly on the trigger, and your eyes watch the gun sights through which in a few seconds an enemy will be flying in a veritable hail of fire." We like, too, the description of a Polish pilot reporting on a shot-down opponent who escaped by parachute: " ' I circle round, bloddy German lies down, he is dead, O.K. But I look again, he is now sitting up, no bloddy good.' He was very disappointed; in his opinion the only good Germans are dead Germans." If there is no great writing in this book, there is at least plenty of incident and a practical schoolboy attitude towards the war that is neatly summed up in the sentence: " It's a very good thing to instil into the Hun a healthy respect for the R.A.F." We are quite certain that Flight Lieutenant Crook and his comrades succeeded in doing this.